THE WASTE ISOLATION PILOT PLANT MISSION: COULD IT BE EXPANDED TO SOLVE OTHER NATIONAL RADIOACTIVE-WASTE-DISPOSAL NEEDS?

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ABSTRACT

The siting, development, licensing/certification/permitting, opening, and operation of disposal systems for long-lived radioactive wastes typically encounter opposition and delays. As a consequence, in terms of having a regulatory approved and/or operating disposal facility/system, there are several *homeless* radioactive waste categories in the United States of America. One exception to this stalemate is the United States (U.S.) Department of Energy (DOE)-operated deep geological disposal system (repository) near Carlsbad, New Mexico, for safe disposal of up to 175,584 cubic meters of long-lived, transuranic radioactive waste (TRUW) at a depth of 655 meters below the ground surface in the lower half of a 250-million-year-old, 600-meter-thick, tectonically and seismically undisturbed, virtually impermeable salt bed at the Waste Isolation Pilot Plant (WIPP) site (Figure 1).

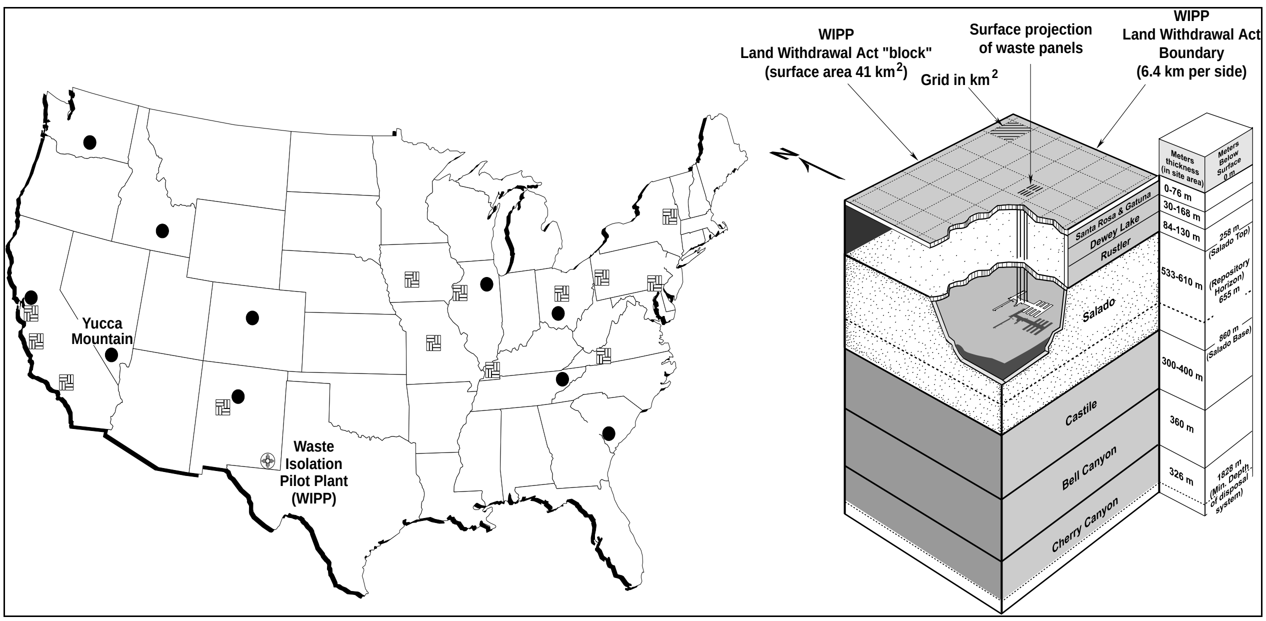

Fig. 1. Locations of 10 large-quantity (circles) and 13 small-quantity (squares) TRUW storage/ generator sites, and the WIPP site (left figure). Schematic illustrations of the WIPP disposal system and its main stratigraphic units (right figure).

The WIPP site has been tested and characterized since 1975 for the potential purpose of hosting a deep geological repository for safe disposal of long-lived radioactive waste. One federal and one state regulator have confirmed that the WIPP site/repository complies with all applicable radioactive and hazardous waste regulations, respectively. Indeed, site-specific, regional, and other data, model results, and analyses strongly suggest that the geology at and adjacent to the WIPP site, and similar geological settings elsewhere, exhibit very favorable characteristics for long-term containment and isolation of any solid, long-lived waste, including ease in developing credible conceptual and numerical models for long-term safety and performance assessments. For example, more than 300 potential natural- and human-induced, post-closure, repository breach features, events, and processes were combined into scenarios, including very-low-probability, phantasmagoric scenarios and assessed, and presented to the U.S. Environmental Protection Agency (EPA) by the DOE in the WIPP compliance certification application. The related total amount of radionuclide releases during the 10,000-year regulatory period is predicted as being less than one-thirtieth of that allowed under the applicable EPA radioactive waste management and disposal regulations. In addition, prior to certifying WIPP, the EPA designed and evaluated a "worst conceivable set of scenarios" in the Performance Assessment Verification Test (PAVT). The PAVT showed that the related total amount of radionuclide releases would be less than one-tenth of that allowed by the aforementioned regulations. The TRUW inventory used in these calculations included about 13 metric tons of plutonium, which is one of the dominating radioisotopes in terms of long-term toxicity in many currently *homeless* radioactive waste categories. Furthermore, the two currently controlling quantitative performance requirements/safety criteria are functions of the types and amounts of radioactive waste constituents destined for the WIPP repository. Consequently, disposal of additional long-lived radioactive waste does not necessarily reduce the current safety factor. Thus, the question arises whether the current mission of the WIPP TRUW repository could be expanded to solve other national radioactive waste disposal needs.

Clearly, the current database and regulatory framework strongly suggest that the geologic setting at the WIPP site could accommodate the disposal of additional quantities of long-lived radioactive waste without compromising the very high level of public health and environmental protection/safety to current and future generations defined in currently applicable radioactive waste disposal regulations. As follows, the scientific/engineering challenges that remain may simply be waste-specific, including the design of a long-term waste recovery system, in the event such a system is required. In other words, the main potential challenges to an expansion of the current WIPP mission appear to be institutional, local, and political acceptance rather than regulatory- or scientific/engineering-related.

INTRODUCTION AND DISCLAIMERS

The 1974 siting, the 1998 certification [1], and the 1999 permitting [2], opening, and operation of the Waste Isolation Pilot Plant (WIPP) deep geological repository for safe disposal of long-lived, transuranic radioactive waste (TRUW) embodies milestone events and achievements of global implications and applications. These milestone events and achievements, augmented by the continued safe operation and future periodic recertifications of the WIPP TRUW repository for another 35 years, offer a broad range of opportunities for other radioactive waste management programs to draw upon the WIPP experience.

Two specific WIPP-experience areas that could contribute to the advancement and success of other radioactive waste management programs currently considering or involved in developing deep geological disposal systems for long-lived radioactive waste are:

1. Approaches to increase public and political understanding and acceptance of deep geological disposal of long-lived radioactive waste (the scientific understanding and acceptance are already established around the world).
2. Twenty-five years of existing and 45 years of future WIPP experiences in the siting, site characterization, test designs and experiences, databases, model developments and applications, repository design, operation, and closure, and the related regulatory, public, and political interactions.

As a Signatory of the International Atomic Energy Agency's *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* [3], the United States (U.S.) Department of Energy (DOE), through its Carlsbad Area Office (CAO), has developed a Prospectus [4] outlining a select set of past, current, and future WIPP-related activities and initiatives deemed to be of potential interest and value to other members of the radioactive waste management community. The intention of this Prospectus is to contribute to enhanced nuclear safety worldwide by listing and offering other radioactive waste management organizations the opportunity to identify and share successful approaches, data, models, and experiences vested in the WIPP project.

In addition, both the operating and the long-term (post-closure) safety of the WIPP disposal system/repository were convincingly demonstrated during its 3-year certification and 4½-year permitting processes that included the successful resolution of several related legal challenges. Indeed, the long-term safety of the WIPP TRUW repository was analyzed in the context of a multitude of potential doomsday scenarios that, in turn, were based on more than 300 natural and human-induced features, events, end processes (FEPs), including a set of extremely low probability, phantasmagoric, inadvertent-human-intrusion and natural scenarios. Figure 2 shows the predicted total amount of radionuclide releases from the WIPP TRUW repository during the 10,000-year regulatory period. These releases are less than one-tenth of the limits and other criteria defined in the EPA's framework for disposal of long-lived radioactive waste at the WIPP site [5,6]. It is instructive to note that the same regulatory framework would also apply to spent nuclear fuel and high-level radioactive waste, if they were to be disposed of at the WIPP site.

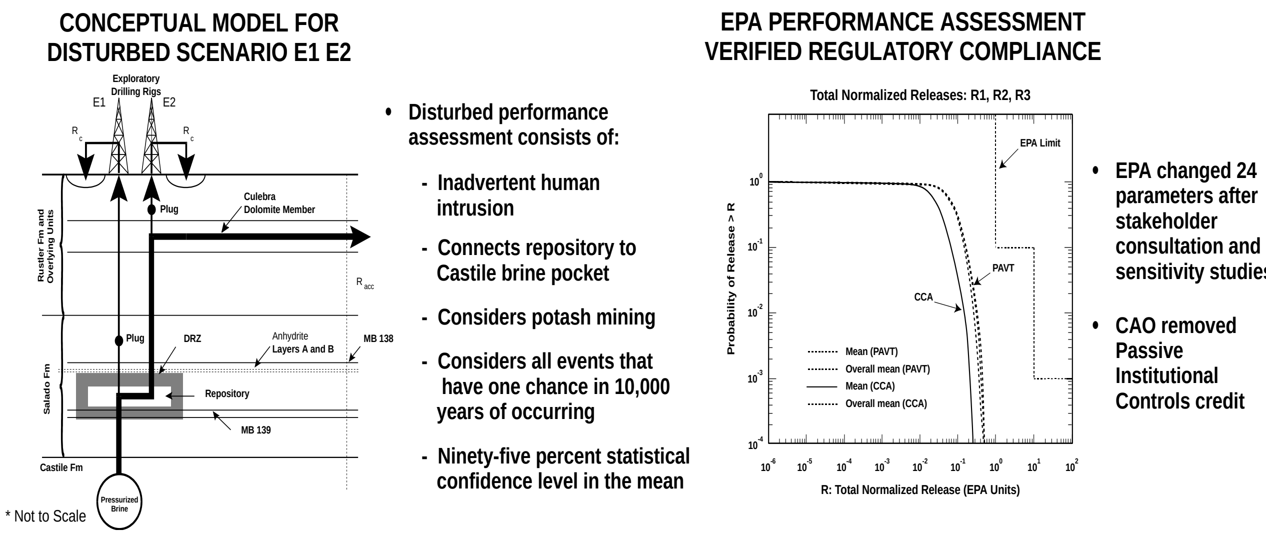

Fig. 2. Schematic illustration of the "highest-consequence" disturbed scenario (left figure). Mean complementary cumulative distribution functions (CCDFs) for all undisturbed and disturbed scenarios in the WIPP compliance certification application (CCA) [7] and the EPA's related Performance Assessment Verification Test (PAVT) (right figure). (Note to the left should read: *Considers all events that have one chance in 10,000 of occurring in 10,000 years*, i.e., the probability of occurrence must be at least 10^{-8}.)

In contrast to TRUW, several other long-lived radioactive waste categories are currently *homeless*, i.e., they either lack a regulatory-approved/certified and operating disposal system or have a history of opposition, delays, and cost-increases during the siting, development, and licensing/certification/permitting, and operation of the related storage and disposal facilities. Furthermore, the current statutory disposal capacity of the WIPP TRUW repository may not accommodate all of the nation's TRUW. Thus, the remaining text addresses the potential expansion of the current WIPP mission to include the disposition of one or more currently *homeless* long-lived radioactive waste categories, including additional TRUW.

One of the two author-chosen bases for the subsequent discussion is the radionuclide containment and isolation provided by the geologic setting. The other is the safety-baseline defined in the regulations forming the basis for the 1998 certification of the WIPP site because, in addition to applying to TRUW, they would also apply to the safe management and disposal of HLW at the WIPP site.

In order to assess the potential ability of the WIPP site/region to provide significant contributions to the containment and isolation of additional long-lived radioactive waste, it is necessary to be familiar with:

1. The current WIPP mission (as defined in applicable laws [8,9] and regulations [5,6]).
2. The WIPP site geology.
3. The current WIPP repository layout.
4. The dominant radionuclides in the TRUW repository in terms of post-closure safety/performance assessments.
5. Fundamental safety definitions in the EPA's WIPP-specific disposal regulations [5,6].
6. The WIPP safety case.

The above information is concisely provided below in the BACKGROUND section. The DISCUSSION section that follows provides a *speculative* assessment of the potential to expand the current WIPP mission in terms of:

1. Radioactive waste categories.
2. Current geological setting/land parcel/block.
3. Expanded land parcel/block.
4. Local acceptance.
5. Institutional acceptance.
6. Political acceptance.

The main text ends with a SUMMARY OF CONCLUSIONS followed by a full listing of the REFERENCES indicated by successive Arabic numerals within brackets [1-17] in the text. Key words, terms, and concepts are *italicized* throughout the text.

Disclaimers

This intent of this paper is to initiate a discussion on the expansion of the current WIPP mission. As indicated above, the analyses, discussions, and conclusions provided below are based on the natural barriers at the WIPP site, and the radioactive waste disposal regulations that apply to the WIPP site, as understood by the author.

The selection of the geologic setting is based on the condition that the WIPP safety case presented by the DOE in the WIPP CCA [7] and used in the EPA's related PAVT (Figure 2) virtually exclusively rely on the geologic setting for radionuclide isolation and containment. In addition, it is the author's opinion that it is easier to credibly demonstrate the long-term performance and safety of a repository based on a simple geologic setting than it is on most engineered barriers. Furthermore, if the geological setting alone is able to provide the required containment and isolation of the radionuclides considered, other barriers could and should be designed to accommodate and enhance this protection. In other words, natural and engineered barriers as well as the construction, operation, and thermal loading of a deep geological repository should be designed to minimize the disturbance to the geological setting [10].

The current regulatory framework for disposal of TRUW at the WIPP site [5,6] is very stringent and applies to a broad range of radionuclides. It is, thus, the author's opinion that, even if these regulations don't directly apply to any given *homeless* waste category, the related WIPP safety case may be used for a preliminary viability assessment of the WIPP site's potential to accommodate the disposal of additional waste, including many currently *homeless* radioactive waste categories.

In summation, this text neither attempts to address the complete disposal system, i.e., both natural and engineered barriers, nor all potential *homeless* waste categories that may be considered for disposal at WIPP. However, the geological setting at the WIPP site is not unique and the current WIPP radioactive waste disposal regulations likely bound the radionuclide content of most *homeless* long-lived radioactive waste categories. Consequently, although the main bases for the subsequent discussion are site- and regulatory-specific, it should apply to many currently *homeless* long-lived radioactive waste categories and, possibly, to other salt-sites both in the United States of America (USA) and elsewhere.

Lastly, the reader is emphatically advised that:

- All observations, comments, conclusions, and recommendations presented in this text are solely attributable to the author unless otherwise indicated by direct reference to the appropriate source(s)/reference(s); and
- The author is biased in favor of (a) deep geologic disposal of long-lived *WASTE* and (b) an expansion of the WIPP mission. (The word "waste" is emphasized to denote another author bias, i.e., spent nuclear fuel is not necessarily a waste.)

BACKGROUND

Presented below is the framework of WIPP conditions deemed most applicable to the discussion on the expansion of the WIPP mission.

The Current WIPP Mission

The current statutory mission of WIPP is defined in Public Law 97-425 [8], as amended in Public Law 102-579 [9]. These laws include directions to the DOE to develop and operate a deep geological repository at the WIPP site in compliance with applicable laws and regulations, including those to be developed by the EPA. Thus, the WIPP mission is essentially defined in the aforementioned laws and EPA regulations [5,6] as follows:

- A 41.6 square kilometer (km^2) surface-area, land parcel, the WIPP site, has been set aside by the U.S. Congress for the development, operation, and closure of a deep geological repository that may contain up to 175,584 cubic meters (m^3) of post-1970, defense-related, TRUW. (As illustrated in Figure 1, a separate agreement between the State of New Mexico and the DOE limits the depth of the WIPP disposal system, also referred to as the "*controlled area*" and "land block", to 1,830 m).
- TRUW contains man-made radionuclides with
  - atomic numbers higher than uranium (transuranic),
  - a minimum half-life of 20 years, and
  - an activity level of at least 3,700 becquerels (Bq) per gram of waste but not exceeding a surface dose rate (measured at the outside of the container/canister) of 10 sieverts per hour (Sv/h).
- There are two TRUW categories: contact handled (CH) and remote handled (RH). CH-TRUW may not and RH-TRUW must exceed a surface dose rate of 0.002 Sv/h.
- The amount of RH-TRUW is limited both in terms of volume and radioactive activity. Its activity may not exceed (a) 8.51×10^{10} Bq per liter (averaged over the volume of the canister) or (b) a total of 18.87×10^{16} Bq.

The WIPP Site Geology

The geology at and adjacent to the WIPP site is described in great detail in the WIPP CCA [7]. A condensed description of the WIPP site geology is provided below.

The WIPP site is located on an arid, generally flat plain covered with sand, caliche, and desert bushes in the northern portion of the Delaware Basin in New Mexico (Figure 1). The stratigraphic column at the WIPP site comprises about 4,575 m of Paleozoic sedimentary rocks on top of the Precambrian basement rock. As shown in Figure 3, the formations of interest with respect to the WIPP repository, from the youngest/shallowest to the oldest/deepest, are:

1. The Pleistocene Gatuna Formation;
2. The Upper Triassic Santa Rosa Sandstone Formation that tapers from the east to the west across the WIPP site;
3. The Dewey Lake, Rustler, Salado, and Castile formations of the Permian Ochoan Series; and
4. The Bell Canyon Formation of the Delaware Mountain Group.

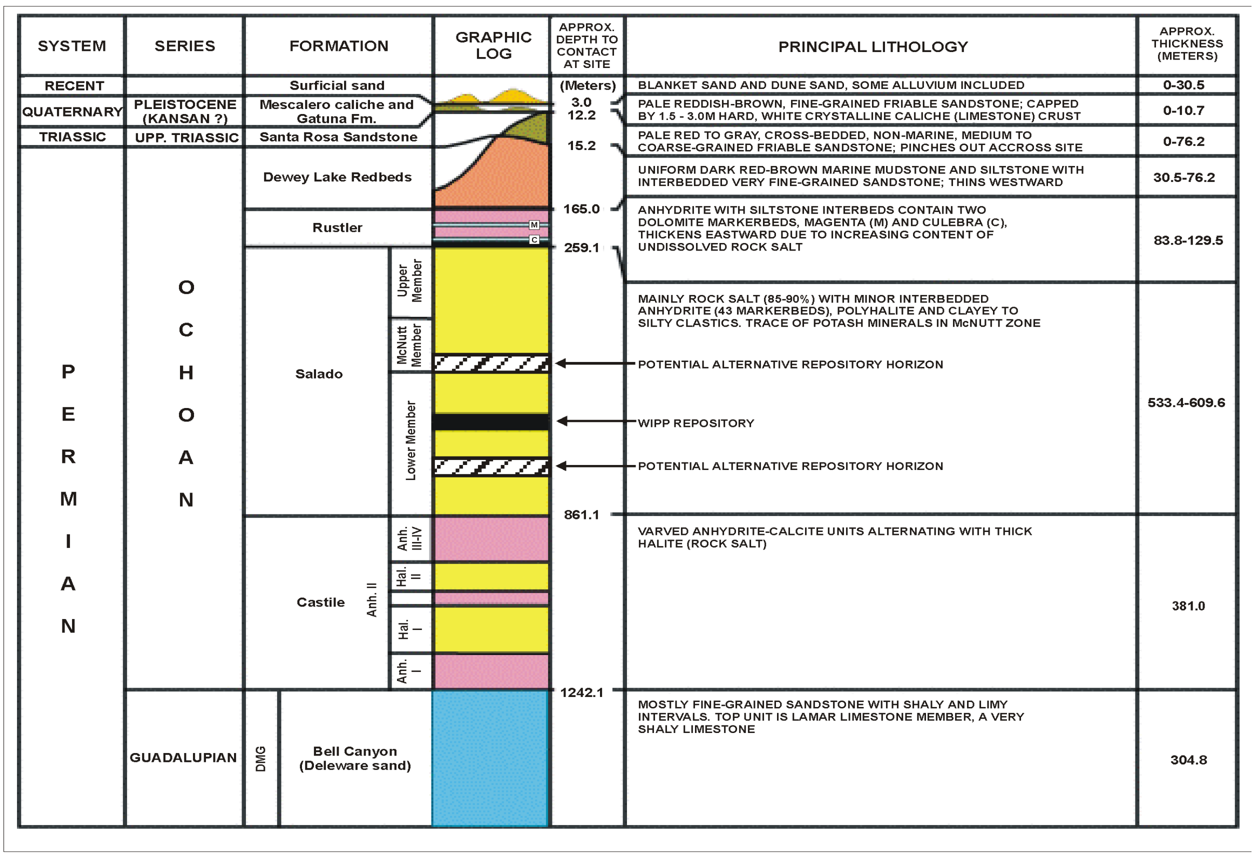

Fig. 3. Generalized stratigraphy at the WIPP site.

The Rustler Formation, which overlies the Salado Formation, contains the most important geohydrologic units in the region. The thickness of the Rustler Formation varies between 84 m to 130 m in the northern Delaware Basin and is approximately 95 m thick at the WIPP site. It contains three recognized fluid-bearing zones: the Rustler-Salado Contact Residuum, the Culebra Dolomite, and the Magenta Dolomite (shallowest). Available field data indicate that the transmissivity of the Culebra Dolomite is the highest, followed by the Magenta Dolomite, and the Rustler-Salado Contact Residuum. The water quality is highly variable within each unit. The total dissolved solids concentration is lowest in the Magenta Dolomite and highest in the Rustler-Salado Contact Residuum. Nearly all the water in the Rustler Formation at the WIPP site has total dissolved solid (TDS) concentrations greater than 10,000 milligrams per liter (mg/l).

All three hydrologic units in the Rustler Formation probably discharge 22 km to the southwest near the Malaga Bend into the Pecos River. The recharge areas are identified rather imprecisely as being upgradient of the measured hydraulic heads, about 16 to 24 km north of the WIPP site. At the WIPP site, the three units are separated, but are probably interconnected in Nash Draw, west and southwest of the WIPP site. Of the three Rustler units, the Magenta Dolomite and the Culebra Dolomite extend across the WIPP site, whereas the Rustler-Salado Contact Residuum mainly produces water west of the WIPP site. The majority of testing in the Rustler Formation has concentrated on the Culebra Dolomite, because it is more transmissive than the Magenta Dolomite and therefore better suited for analyzing "upper bound" radionuclide release scenarios for the WIPP TRUW repository.

Results of several single- and multiple-hole flow tests at the site indicate that the transmissivities of the Culebra Formation at and near the WIPP site range between 10^{-3} meter square per second (m^2/s) in Nash Draw to 10^{-8} m^2/s east of the WIPP site. Generally, the transmissivity increases from east to west across the WIPP site. The highest transmissivity zones occur in the southeastern, north-central, and northwestern portions of the WIPP site. The chemical composition of groundwater from the Culebra Formation varies widely within short distances at and near the WIPP site. Three miles south of the WIPP site, the Culebra Formation water typically contains 3,000 mg/l of TDS. At the site itself, the TDS content varies from 12,500 mg/l to 139,500 mg/l. Extreme variation in the chemistry of the Culebra Formation water within short distances is illustrated by TDS concentrations of 12,500 mg/l, 153,500 mg/l, and 118,000 mg/l within a distance of less than 3 km.

As shown in Figures 1 through 3, the repository is situated about 655 m below the ground surface in the lower half of the Salado Formation, which underlies the Rustler Formation and overlies the Castile Formation. The Salado Formation consists primarily of halite with a zone of potassium- and magnesium-bearing minerals (sylvite, langbeinite) and thin (<1 m) seams of clay, anhydrite, and polyhalite. Before 1986, thick salt beds, as in the Salado Formation, were considered essentially dry and impermeable. However, observations from the WIPP excavations show that local seeps occur, which indicates that the salt beds may be saturated with brine and may exhibit Darcian flow, albeit at very low permeability.

The Castile Formation is about 470 m thick at the WIPP site and consists of alternating layers of anhydrite and halite, with four anhydrite and three halite members. The uppermost anhydrite member, situated about 245 m below the repository, locally contains pressurized brine reservoirs that have been indicated by geophysical data and encountered by two of the boreholes drilled for the WIPP project and by several oil and gas exploratory wells adjacent to the WIPP site. Groundwater also occurs in the upper part of the Bell Canyon Formation in poorly cemented sandstone stringers; however, the controlling hydrological conditions for radionuclide transport at the WIPP site are the local, overpressurized brine pockets in the Castile Formation and the transmissive units of the Rustler Formation.

An important site condition to any future well drilling and ingestion of radionuclides is that the saline content of the groundwater at the WIPP site is high and the water is not potable. However, the WIPP site is situated in an area with economic natural resources. Potash minerals are mined around the WIPP site from the McNutt potash zone in the upper part of the Salado Formation, approximately 450 m below the surface, i.e., approximately 200 m above the WIPP repository. Oil and gas are produced around the WIPP site from the Permian Delaware Mountain Group and Pennsylvanian Atokan and Morrowan strata. The presence of local natural resources strongly influences the WIPP TRUW repository safety/performance assessments.

Several natural- and human-induced FEPs were identified during the characterization of the WIPP site that could impact the performance of the repository during the 10,000-year regulatory period. These include salt dissolution, breccia chimneys, brine reservoirs, Salado Formation hydrology, Rustler Formation hydrology, excavation-disturbed rock behavior, and exploration for and extraction of natural resources. These FEPs were combined into scenarios. As indicated above and in Figure 2, the “highest consequence” scenario identified and evaluated in the WIPP CCA and in the EPA's related "bounding" PAVT is an inadvertent drilling through the repository into an underlying brine reservoir in the Castile Formation followed at a later date by another drilling into the same disposal room. The long-term consequences of all of these and several other FEPs were documented by the DOE in the WIPP CCA [7] and were found by the EPA [1] to be adequately represented and well within the performance/safety requirements defined in the applicable disposal regulations [5] and the related compliance criteria [6].

The WIPP Repository Layout

Schematic illustrations of the relationship between the WIPP land parcel/block and the repository, and the WIPP repository layout are shown in Figures 1 and 4, respectively. The horizontal projection (footprint) of the repository is 0.49 km^2. The shortest distance between the repository perimeter and the WIPP land parcel boundary, i.e., the *accessible environment*, is 2.4 km.

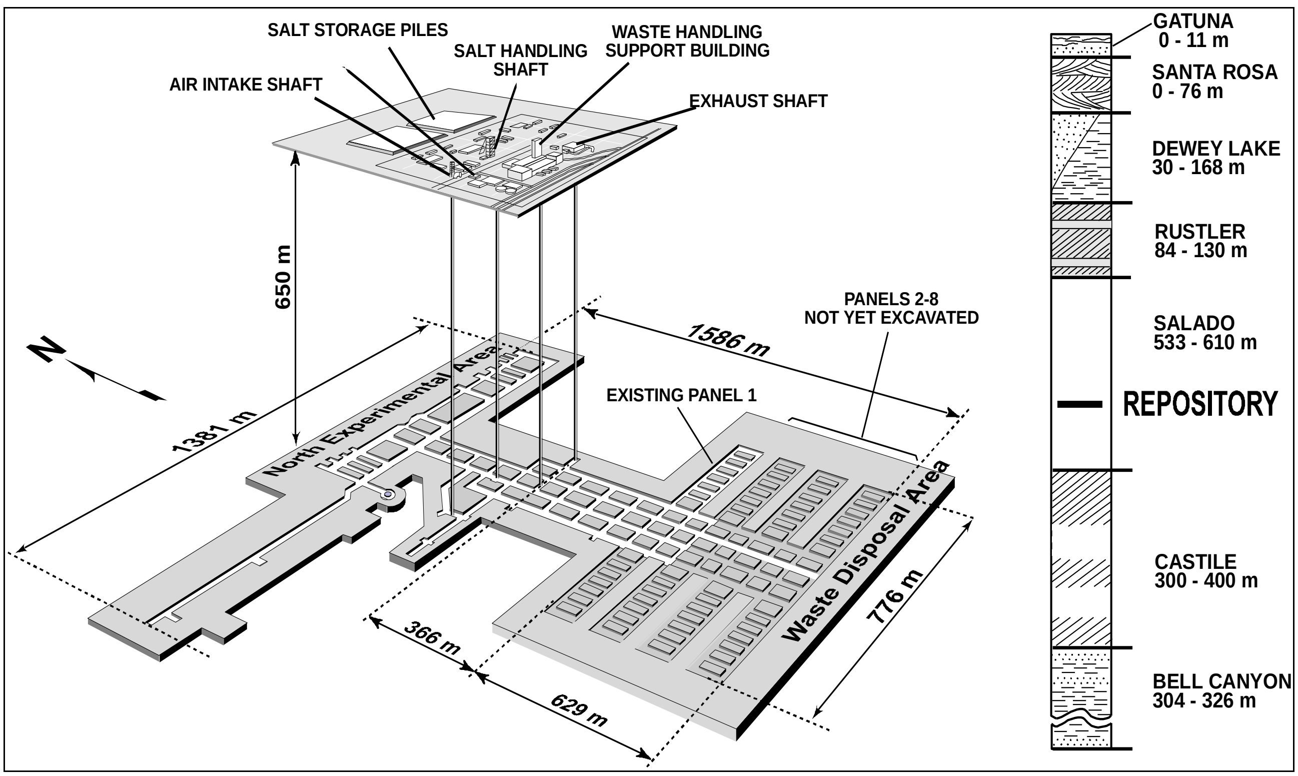

Fig. 4. Schematic illustrations of the baseline WIPP TRUW repository design and the stratigraphy at the WIPP site.

As shown in Figure 4, the baseline repository layout/design comprises eight panels. Each panel hosts seven disposal rooms. Each disposal room measures 4 m in height, 10 m in width, and 91 m in length. At the end of 1999, Panel 1 had been fully excavated and Panel 2 was being excavated. Panels 3 through 8 will be excavated at a later date.

Dominating Radionuclides in the TRUW Repository in Terms of Post-closure Safety/Performance Assessments

The Transuranic Waste Baseline Inventory Report (BIR) [11] contains detailed descriptions and listings of the current radionuclide inventory, and the WIPP Waste Acceptance Criteria (WAC) [12] define the radionuclide inventory/envelope that may be shipped to and accepted at WIPP. Both of these documents are included in the CCA [7]. Table I lists 30 of the most common radionuclides in the existing TRUW [7,11,12,13]. The eleven radionuclides with the highest concentration in Sv/m^3 are indicated in bold text. However, the activity/toxicity of all radionuclides will change with time as a function of their respective amount, half-life, and activity. Since the majority of the radionuclides in current and future TRUW either has a short half-life, low activity, or do not occur in any significant amount, the subsequent discussion focuses on radionuclides that are significant to the outcomes of post-closure safety/performance assessments.

Americium (Am,), Plutonium (Pu), Cesium (Cs), and Strontium (Sr) comprise more than 99 percent of post-closure radionuclide releases [7]. Whereas, the total activity during the 10,000-year regulatory period is dominated by four radionuclides, i.e., Am^{241} and $Pu^{238,239,240}$, the key "bad-actor" safety/performance assessment radionuclides during this period are Am^{241} and $Pu^{239,240,241}$. After 10,000 years, the two main contributors to the total activity of the waste are $Pu^{239,240}$. The projected amount of Pu, which has a half-life of up to 24,065 years, to be disposed of at WIPP is about 13 tons.

Table I. Dominating Radionuclides in currently stored TRUW.

Actinium (Ac) 225, 227	**Cobalt (Co) 60**	Promethium (Pm) 147
Americium (Am) 241, 243	**Curium (Cm)** 243, **244**, 245	Protactinium (Pa) 233, 234m
Antimony (Sb) 125	Europium (Eu) 152, 154, 155	Radium (Ra) 224, 225, 226
Barium (Ba) 137m	Francium (Fr) 221	Radon (Rn) 220, 222
Bismut (Bi) 210, 212, 213, 214	Krypton (Kr) 85	Ruthenium (Ru) 106
Cadmium (Cd) 109	Lead (Pb) 209, 210, 212, 214	**Strontium (Sr) 90**
Californium (Cf) 252	Neptunium (Np) 237, 239	Technetium (Tc) 99
Carbon (C) 14	Nickel (Ni) 63	Thorium (Th) 228, 229, 231, 234
Cerium (Ce) 144	**Plutonium (Pu), 238, 239, 240, 241,** 242	Uranium (U) 232, 233, 234, 235, 237, 238
Cesium (Cs) 134, **137**	Praseodymium (Pr) 144	**Yttrium (Y) 90**

Fundamental Safety Definitions in the EPA's WIPP-specific Disposal Regulations

The safety basis for the EPA's disposal regulations [5] is 1,000 repository-induced cancer deaths during the 10,000-year regulatory period among a population of 10 billion people, i.e., the related cancer-death risk factor is 10^{-11}. The EPA's disposal regulations, i.e., Code of Federal Regulations Title 40, Part 191 (40 CFR 191), provide four specific, quantitative safety criteria. One safety criterion pertains to undisturbed repository performance (40 CFR 191.15 - Individual Protection), two safety criteria pertain to the cumulative effects and consequences of undisturbed and disturbed repository conditions (40 CFR 191.13 - Containment), and one criterion pertains to groundwater protection (40 CFR 191 Subpart C). However, as indicated above, the groundwater at and adjacent to the WIPP site is typically non-potable and contains a higher content of TDS than the 10,000-milligram-per-liter limit defined in the applicable regulation. Thus, this particular regulatory requirement is of marginal importance and the subsequent discussion focuses on the other three quantitative safety criteria.

The quantitative individual protection requirement in 40 CFR 191.15 reads:

"(a) Disposal systems for waste and any associated radioactive material shall be designed to provide reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual committed effective dose, received through all pathways from the disposal system, to any member of the public in the accessible environment, to exceed 15 millirems (150 microsieverts)."

The quantitative containment requirements in 40 CFR 191.13 read:

"(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive waste shall be designed to provide a reasonable expectation based on performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that might affect the disposal system shall:

(1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and
(2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A)."

For example, 40 CFR 194.34(d) reads:

"The number of CCDFs generated shall be large enough such that, at cumulative releases of 1 and 10, the maximum CCDF generated exceeds the 99^{th} percentile of the population of CCDFs with at least 0.95 probability. Values of cumulative releases shall be calculated according to Note 6 of Table 1, Appendix A of Part 191 of this chapter."

Furthermore, 40 CFR 194.34(f) reads:

"Any compliance application shall provide information which demonstrates that there is at least a 95 percent confidence level of statistical confidence that the mean of the population of CCDFs meets the containment requirements of paragraph 191.13 of this chapter."

The relief from calculating the long-term effect and consequence of every conceivable, and inconceivable, FEP and scenario is defined in 40 CFR 194.32(d) as follows:

"Performance assessments need not consider processes and events that have less than one chance in 10,000 of occurring over 10,000 years."

In summation, the 1998 certification, continued operation, and pending recertifications of the WIPP site/repository are:

- Site specific;
- The underlying radioactive waste disposal regulations [5] and compliance criteria [6] apply to TRUW, spent nuclear fuel, and HLW; and
- Very stringent.

The WIPP Safety Case

The WIPP safety case presented in the CCA [7], augmented by related PAVT calculations, convincingly demonstrated that the WIPP TRUW repository readily complied with all applicable safety requirements.

For example, the calculated maximum annual committed effective dose to an individual was 0.0047 mSv, which is ~1/32nd of the dose defined as safe by the EPA in 40 CFR 191.15. Similarly, several safety/performance assessments were made in the CCA and in conjunction with the EPA's review of the CCA. The results of these calculations are summarized in Figure 2. Suffice it to mention that the "upper bound" of radionuclide releases derived form the PAVT calculations are more than one order of magnitude lower than the related EPA limits in 40 CFR 191.13. The more realistic, yet very conservative, radionuclide releases calculated in the CCA [7] are about one-third of those calculated in the PAVT.

DISCUSSION

Similar to the development and operation of any radioactive waste management and disposal facility, an expansion of the WIPP mission would be essentially governed by a combination of science and engineering in an attempt to comply with applicable safety requirements on one hand and societal actions and reactions on the other. However, whereas the fundamental scientific and engineering safety basis is to ensure a high level of environmental radiation protection for current and future generations and environments, the related bases for societal actions and reactions are much broader and less transparent.

The ensuing discussion addresses three essentially scientific and engineering-related issues and three essentially societal issues and conditions deemed by the author to be of particular significance to the potential expansion of the WIPP mission. Although these issues are addressed individually under separate headings, they are all closely interrelated and typically growing in importance with time in the order they are discussed.

Radioactive Waste Categories

In terms of expanding the WIPP mission, one of the most important implications of the 40 CFR 191.13 containment requirements definitions is that *the two safety criteria for the cumulative effects and consequences of undisturbed and disturbed repository conditions*, which typically govern all post-closure safety assessments, *are normalized relative to the amount of waste disposed of in the repository, i.e., the more waste that is emplaced the greater is the allowable integrated release of radionuclides*. Consequently, even if more long-lived radioactive waste is emplaced in the WIPP repository than that currently allowed under the applicable law [8], the radionuclide-release safety factors established in the WIPP CCA [7] and the PAVT (Figure 2) may remain very high.

As illustrated in Table I, the radionuclide content/inventory of the existing TRUW is the same as for many currently *homeless* long-lived radioactive waste categories. Furthermore, this radionuclide inventory/envelope may be expanded and, possibly bounded upwards by the inventory and methods for calculation described in Appendix A of 40 CFR 191. Conversely, if the lower limit for TRUW, i.e., 3,700 Bq/gram etc., was lowered to 370 Bq/gram (10 nanocuries/g), significant amounts of existing, currently *homeless*, comparatively benign, long-lived radioactive waste could be accommodated in the WIPP repository [14], disposal space permitting (see below).

It should be noted that the initial objective of the site characterization and in situ testing program at the WIPP site was designed to establish the radionuclide containment and isolation characteristics of the prevailing geology as they pertain to both TRUW and HLW. For example, the Thermal/Structural Interaction Test program included simulated defense-HLW (DHLW) tests such as the 18-Watt/m^2 DHLW Mockup, the DHLW Overtest, and the Heated Axisymmetric Pillar and Geomechanical Evaluation in the candidate repository host rock [15]. Likewise, the Simulated DHLW Technology Experiments included 18 in situ DHLW waste package performance tests at elevated temperatures, as did the Moisture Transport and Release Tests.

Although the effects of thermal loading have been investigated and analyzed in the current repository horizon, the related data and models are almost 10 years old and need to be updated based on more recent data and models from other salt repository sites/programs. Furthermore, structural stability of openings during the pre-closure phase could also be a challenge in the long-term physical access to the waste is considered. Consequently, contingent upon the waste category considered, it might be necessary to conduct additional tests and model development.

In summation, other than the potential physical effects and requirements emanating from heat-generating waste and/or long-term physical access to the emplaced waste, there is no apparent constraint to an expansion of the current WIPP WAC envelope. However, additional waste-category-based studies would likely be required.

Current Land Parcel/Block

This and the next session section focus on physical options to expand the WIPP disposal capacity. The discussion in this section is based on the premise that current boundaries for the WIPP land parcel/block remain unchanged. The subsequent section discusses the potential to expand the horizontal projection of the WIPP land parcel/controlled area. Suffice it to reiterate that, based on the WIPP safety case, the PAVT, and the proportionality of the regulatory radionuclide release limits, it is apparent that the geologic setting within the current land parcel/block readily could facilitate additional amounts of long-lived radioactive waste without exceeding the very prescriptive and stringent safety and compliance criteria defined by the EPA in 40 CFR 191 [5] and 40 CFR 194 [6], respectively.

The current WIPP land parcel/block and the repository layout are schematically illustrated in Figures 1 and 4, respectively. The current disposal scheme is to stack the CH-TRUW containers/packages in the disposal rooms and to place the RH-TRUW containers in holes in the walls between the disposal rooms. There are at least four physical options to accommodate an expansion of the WIPP mission in terms of accommodating additional types and amounts of long-lived radioactive waste within the current WIPP land parcel/block. They are:

1. A higher waste-loading density per unit volume of the repository.
2. The construction of additional disposal space adjacent to current repository.
3. The construction of additional disposal space above and/or below the current repository horizon.
4. A combination of options 1 through 3.

Options 1 through 3 are discussed further below.

The major current regulatory constraint to a higher waste-loading density appears to be the regulations pertaining to the shipping/transportation of the waste rather than the disposal regulations. The major physical constraint is the lack of free space/disposal volume in the current repository. However, the average void space in the existing CH-TRUW containers is about 80 percent. Thus, barring any related proliferation and criticality issue, compacting portions or most of the CH-TRUW and any additional *homeless* waste is one apparent potential physical option to accomplish a higher waste-loading density within the current repository. In the event current shipping/transportation constraint(s) cannot be mitigated, the compaction could be done at the WIPP site. Another option is to increase the waste-loading density in the walls of the repository.

As indicated in Figure 4, the potential for expanding the current repository in a northerly direction is limited due to the existence of and continued need for the four shafts and the existence of an experimental facility. There is also a distant solution front north of the shafts that governed the relocation of the current repository to the south of the shafts. Thus, the most promising direction for an expansion of the repository is to the south of the current repository. However, any southerly expansion would decrease the containment and isolation barrier provided by the geological setting. Since this natural containment and isolation barrier may be crucial for compliance with applicable disposal regulations, there might be a limit for a southerly expansion of the repository. There may also be ventilation and muck-handling constraints limiting a southerly expansion. However, they may be alleviated by the construction of one or more additional shafts.

As illustrated in Figures 1 through 4, there is ample room in the current WIPP-repository host formation, the Salado Formation, for the construction/excavation of additional levels of disposal volume above and below the current repository elevation. Incidentally, a multiple-level repository for TRUW and DHLW disposal has been previously considered e.g., at a depth of about 800 m in the Infra-Cowden at the bottom of the Salado Formation [16].

There is, however, a potential generic geologic-setting constraint to long-term physical access, monitoring, and intact recovering of the emplaced waste. One stated reason for the National Academy of Sciences' 1957 recommendation for the nation to pursue rock salt as the prime host rock for long-lived radioactive waste disposal considerations was/is its rheological characteristics, i.e., rock salt deforms/creeps with time under very low differential stresses [17]. Whereas, it is beneficial in terms of its ability to efficiently close openings in rock salt and encapsulate the emplaced waste, rock salt creep limits the period of physical access to the emplaced waste, unless rigid structures are in place to control room closures. Furthermore, the deformation/creep rate increases with increased thermal loading/rock temperature and depth/stress.

Thus, the main issue in terms of disposing heat-generating, long-lived radioactive waste in rock salt is whether maximum containment and isolation or physical access and easy of recoverability is most important. The scientific/engineering answer to this issue is simple; i.e., safety (containment and isolation) comes first; however, the political and public answer(s) may be different. Incidentally, time and cost permitting, any waste emplaced in an underground salt cavity/opening can be recovered.

Expanded Land Parcel/Block

Pursuant to the EPA regulations for safe disposal of spent nuclear fuel, TRUW, and HLW [5] at the WIPP site, the horizontal projection of the controlled area may comprise an arbitrarily shaped surface land parcel of up to 100 km^2. However, pursuant to Public Law 97-102, as shown in Figure 1, the current WIPP land parcel, i.e., *the controlled area*, is only 41.6 km^2. As follows, contingent upon the approval of the U.S. Congress, one cost-effective option for expanding the disposal capacity of the WIPP repository would be to increase the WIPP land parcel to accommodate a related expansion of the repository footprint. However, the current WIPP site is surrounded by active natural resource leases and operations that, at least temporarily, limit and possibly exclude an expansion of the WIPP land parcel until existing resources have been recovered. Consequently, a near-term WIPP-mission expansion may have to be facilitated within the current land parcel/block.

Public Acceptance

One of the most appealing non-scientific/engineering conditions of the WIPP site is the long-standing acceptance and support provided to its development by the local population in the WIPP region. There are, however, enclaves of opposition to WIPP in other parts of New Mexico. Indeed, a particularly interesting and possibly globally unique condition/phenomenon in terms of public acceptance is that, in the State of New Mexico, opposition to WIPP seems to increase upwind and upstream with distance away from the WIPP site. The local population is well educated in matters related to radioactive waste disposal and favorably inclined to regional development and sustenance. Consequently, the local population may also be favorably inclined to an expansion of the WIPP mission if appropriate assurances, such as those for TRUW disposal, can be extended for the expanded facility. On the other hand, such an expansion likely will experience opposition from other, more distant, portions of New Mexico and elsewhere.

Institutional Acceptance

Institutional acceptance of an expansion of the WIPP mission might be the most difficult to achieve, because an expansion of the WIPP mission would likely (a) reduce the scope and power of one or more existing institutions and (b) convey a message that affected institutions have failed in their mission. However, a broad-based institutional acceptance might not be necessary to overcome institutional parochialism since the WIPP mission is defined/legalized by the U.S. Congress and all federal institutions are obliged to comply with its directives, which leaves one to contend with only state institutions. The most important state institution is the NMED. Although the NMED has no statutory regulatory or oversight authority over radioactive waste disposal at the WIPP site, the NMED's acceptance of the WIPP mission should be sought because, if obtained, it would likely reflect the Governor's position and, thus, greatly affect political acceptance, particularly in New Mexico.

Political Acceptance

The political acceptance and support of the WIPP mission has always been strong in the local communities. However, similar to public acceptance, with increased distance from the WIPP site, there are political enclaves of opposition. In light of the pending election in the fall of year 2000, it would be grossly premature to speculate on the potential political support of an expansion of the WIPP mission. Suffice it to mention that present state representatives, both in New Mexico and Washington, D.C., have expressed support for the current WIPP mission.

SUMMARY OF CONCLUSIONS

Based on the above text and pending detailed waste-category-specific analyses, the author's four main preliminary conclusions relative to a potential expansion of the WIPP mission are:

1. ***Extend the waste envelope.*** There are no apparent operational or public health issues that would prevent an expansion of the WIPP mission in terms of waste categories. Additional radioactive waste categories could be readily accommodated within the radiation protection safety levels defined by the EPA in the applicable radioactive waste disposal regulations.
2. ***Increase the disposal volume.*** There are no apparent scientific, engineering, or public health issues that would prevent an expansion of the WIPP mission in terms of waste disposal volume. Additional volumes of radioactive waste could be readily accommodated within the current site boundaries and the radiation protection safety levels defined by the EPA in the applicable radioactive waste disposal regulations. Contingent upon waste category, additional disposal volume could either be developed at, below, or above the current repository level.
3. ***Institutional acceptance is likely to be the main challenge***. Although the current WIPP mission is largely accepted by the public and elected political officials, an expansion of the WIPP mission might not be equally well accepted by affected federal institutions, particularly if the entity is or feels depleted in terms of power and resources.
4. ***The U.S. Congress controls the WIPP mission***. Any extension of the WIPP mission requires a statutory amendment to the LWA by the U.S. Congress and subsequent approval by the President of the USA. Historically, this has not been a predicament.

The final conclusion is that an expansion of the WIPP mission would reduce radiation risks to current generations without compromising public health in the future. Thus, it should be a societal, i.e., Congressional, imperative to ***expand the WIPP mission***.

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